v. Beam Loading Considerations

Acceleration rf System

The static beam loading during acceleration will, in general, not be problematic, since the power given to the beam is less than the power needed to excite the cavity to full voltage. However, during injection of protons, the nominal gap voltage is reduced to only 8.5 kV per station, whereas the voltage induced by a proton beam can be as high as 49 kV for the unloaded cavity (short proton bunches of full nominal intensity, average current 71.3 mA.

One method to reduce the beam induced voltage is the use of an rf amplifier with low output impedance of about 100 kΩ implemented by a triode with split grid neutralization. The beam induced voltage is then about equal to the nominal gap voltage, i.e. at the stability unit.

The other method is local rf feedback with a high-gain tetrode as final amplifier. The induced voltage may be reduced to only 0.38 kV under the same conditions and with similar expenditure, assuming that the total loop delay can be held below 500 nsec (or about 150 m of air-cable). RF feedback is the preferred solution, since it offers not only a comfortable margin for future intensity upgrade, but also attenuates any amplifier imperfections such as parasitic 60 Hz modulations. Last but not least, it allows a much more precise control of the overall cavity voltage so that additional feedforward compensation or counterphasing are easier to apply, if needed.

The maximum permissible beam-induced voltage during the storage process, where the 28.15 MHz system is nominally "off" is as high as 50 kV per station and, therefore, of no concern.

Storage rf System

The total beam-induced voltage of the 197.05 MHz system must be kept below 5 kV at the flat top prior to the bunch rotation and below 10 kV at transition. The former requirement is relatively easy to satisfy, since the bunches are long and their spectral component at 197.05 MHz is very small; the latter, however, represents a major design challenge.

With a bunch length of about 3 nsec at transition, a DC beam current of 71.3 mA leads to an AC component of about 76 mA at 197.05 MHz. The voltage induced in a single 8.9 MΩ cavity is therefore 380 kV, about 300 times the permissible value. This factor will become correspondingly larger for any upgrade in beam intensity and/or addition of cavities should higher rf focussing voltage be necessary.

Counterphasing groups of cavities can provide a reduction of about an order of magnitude under operating conditions. This practical limit applies since the total cavity voltage, although mainly governed by the amplifier excitation, is still significantly influenced by the beam so that precise cancellation is impossible. Additional means of reducing the induced cavity voltage by at least another order of magnitude have to be implemented.

The CERN cavity is equipped with a movable damping loop that can be inserted during transition and slowly withdrawn during the flat top just prior to bunch rotation. Voltage reduction factors in excess of 500 can be achieved with this device. Problems with the bellows have indeed been reported for fast acting units, since high acceleration rates tend to induce mechanical shock waves in the elastic walls which develop micro-leaks; in the present application, however, the loop movement can be extended over several seconds so that fully satisfactory reliability can be expected.

Local rf feedback is again the preferred solution, since the same additional benefits as for the 28.15 MHz system can be gained. Voltage reduction factors (i.e. loop gains) in excess of 150 are theoretically possible for realistic assumptions of the total loop delay.

Actual model measurements in an R&D program are needed to settle all details and to devise the optimum combination of the above mentioned methods.

Control Signal Considerations

In the storage mode it is assumed that essentially no dilution of the bunch width occurs. This requires that the rf signal contain very little noise at multiples of the synchrotron frequency around 197.15 MHz (f_s = 57-227 Hz for 100 GeV/u Gold) and at those sidebands spaced by multiples of f_o within the bandpass of the cavity. Since the buckets will be nearly filled by the bunches all the time there will be a large spread in synchrotron frequencies present. This will put a tight requirement on the allowed noise level. A single bunch phase lock loop and low noise voltage controlled oscillator, along with a low noise frequency control loop as used on the CERN SPS collider, will be employed to reduce the effects of noise on all of the bunches.

The error signal that will be used in generating the correction voltage to be applied to the wideband cavity will be obtained by measuring the radial position variation of each bunch at a dispersion maximum location. The digitized position signal will control the amplitude of a burst of three to six cycles of the 28.15 MHz rf frequency. For a 10^{-4} error in $\Delta p/p$ one obtains $\Delta x = X_p(\Delta p/p)$ = 0.15 mm which is ~4×10^{-3} of the 38 mm radius of the strip line position monitor. Assuming 12 bit digitization full scale, the LSB corresponds to ~9 µm so that an appropriate choice for switching from non-linear to linear feedback would be at the two bit or 19 µm level. This degree of resolution has been achieved with similar sized pickups in the CERN SPS and thus should be an attainable design goal.